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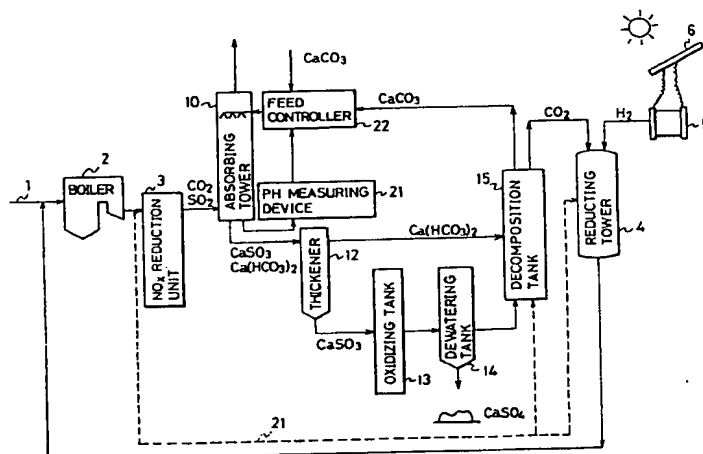
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Recycling system for the recovery and utilization of CO<sub>2</sub> gas.

Described herein is a method for the treatment of flue gas. In this method, flue gas containing CO<sub>2</sub> gas and SO<sub>x</sub> gas is brought into contact with an absorbent containing an alkaline earth metal compound, whereby the gases are both recovered as the carbonate and the sulfite of the alkaline earth metal, respectively. Further, the CO<sub>2</sub> gas produced from

the decomposition of the carbonate can be reduced with hydrogen, whereby a CO<sub>2</sub> reduction product such as a hydrocarbon or an oxygen-containing hydrocarbon is formed to achieve the recycling of the CO<sub>2</sub>. A system suitable for use in practicing the method is also described.

FIG. 1



## 1. Field of the Invention

This invention relates to a system which recovers and utilizes CO<sub>2</sub> gas contained in flue gas such as combustion gas, thereby reducing the quantity of CO<sub>2</sub> gas emitted into the atmosphere and hence contributing to the solution to the green house effect.

## 2. Description of the Related Art

In recent years, the green house effect caused by CO<sub>2</sub> gas has become a worldwide problem and countries everywhere are working together to find solutions. Those proposed so far can roughly be classified into the following approaches: (1) the promotion of energy saving, (2) the development and introduction of new energy; and (3) the fixation and utilization of CO<sub>2</sub> gas. The present invention relates to the third approach.

As a method for the fixation and utilization of CO<sub>2</sub> gas, what may be conceived, for example, is to separate and concentrate CO<sub>2</sub> gas, exhausted as the combustion gas of fossil fuel, and then to reduce it into various substances such as methane and methanol.

A process has been proposed for the separation and concentration of CO<sub>2</sub> gas, in which CO<sub>2</sub> gas is absorbed in an alkaline solution such as monoethanolamine or a potassium carbonate solution and the resulting solution is then heated to release CO<sub>2</sub> gas. Moreover, monoethanolamine is prone to decomposition and substantial thermal energy is required to heat the CO<sub>2</sub>-absorbing solution. The above process is therefore accompanied by potential problems such that energy consumption may be increased, offensive odor may be generated by the product of decomposition and deleterious effects may arise with the processing state, i.e., the CO<sub>2</sub> gas reduction. There is a still further disadvantage that the above absorbents are both strongly corrosive. In addition, when the combustion gas also contains acid gas such as sulfurous acid gas, the acid gas firmly bonds to the absorbent so that CO<sub>2</sub> gas cannot be separated and recovered easily. The absorbent therefore loses its effectiveness rapidly. Accordingly, the above conventional process cannot be applied in this case.

In addition, another process using an adsorbent such as zeolite has also been proposed for the separation and concentration of CO<sub>2</sub> gas. In this process, the adsorption of CO<sub>2</sub> gas is inhibited by oxygen and steam, which are also contained in the combustion gas. For an adsorption reaction, lower temperatures are desirable. The temperature of flue gas is, however, generally 100°C or higher, leading to the drawback that a large adsorption tower is

required. Moreover, when CO<sub>2</sub> gas contains acid gas such as sulfurous acid gas, the acid gas firmly bonds to the adsorbent, thereby gradually reducing the CO<sub>2</sub>-absorbing capacity of the adsorbent. In this case, the above conventional process cannot be applied, either.

Moreover, the reduction of CO<sub>2</sub> gas requires considerable energy input because CO<sub>2</sub> gas is stable. Some attempts have been made to utilize solar energy for the above purpose. In an illustrative system in which CO<sub>2</sub> gas is reduced with hydrogen in the presence of a photocatalyst to convert it to methanol or methane, however, the energy utilization rate is as low as about 0.1%. Such a low efficiency of energy conversion can be attributed to the following causes: (1) A photocatalyst can absorb only light not longer than 420 nm in wavelength so that light in the visible to infrared range is not utilized. (2) No practical catalyst has yet been developed for the acceleration of the reduction reaction of CO<sub>2</sub> gas with hydrogen.

Techniques known in the above-mentioned type of field, for example, separation and concentration techniques for CO<sub>2</sub> gas by an absorbing solution, include those disclosed in Publications of Unexamined Japanese Patent Application (KOKAI) Nos. 69586/1979, 169920/1984 and 10330/1984.

## SUMMARY OF THE INVENTION

With the foregoing problems of the related art in mind, the present inventors have developed the present invention.

A first object of this invention is to provide a method and system effective for reducing the quantity of CO<sub>2</sub> gas emitted from a fossil fuel burning facility, such as a thermal power plant, by separating and concentrating CO<sub>2</sub> gas discharged from the fossil fuel burning facility, reducing the CO<sub>2</sub> gas to methane, methanol or the like and recycling it as fuel.

A second object of this invention is to provide a method and system in which CO<sub>2</sub> gas is separated and recovered efficiently, especially from flue gas containing sulfurous acid gas in addition to CO<sub>2</sub> gas, and is recycled effectively as fuel.

In one aspect of this invention, there is thus provided a method for the treatment of flue gas containing CO<sub>2</sub> gas and SO<sub>x</sub> gas, which comprises bringing the flue gas into contact with an absorbent which contains an alkaline earth metal compound, in order to recover the CO<sub>2</sub> gas and SO<sub>x</sub> gas as the carbonate and sulfite respectively of the alkali earth metal.

Examples of flue gas include the combustion gases of fossil fuel emitted from thermal power plants and the like. Fossil fuel and the like contain carbon and sulfur as components so that their

combustion gases contain CO<sub>2</sub> gas and SO<sub>x</sub> gases such as sulfurous acid gas.

Upon recovery of the carbonate and the sulfite, it is preferable to control the feed quantity of the absorbent so that the reaction system can be maintained at a pH where at least one of the compounds, either the carbonate or the sulfite, is present in a solid form.

The carbonate of the alkaline earth metal is separated from the sulfite and then decomposed into CO<sub>2</sub> gas and the alkaline earth metal compound, thereby making it possible to recover CO<sub>2</sub> gas and also to regenerate the alkaline earth metal compound into the absorbent.

In a further aspect of this invention, there is also provided a method for the regeneration of CO<sub>2</sub> gas, which comprises reducing CO<sub>2</sub> gas, which has been obtained according to the above aspect, with hydrogen to form a CO<sub>2</sub> reduction product such as a hydrocarbon, e.g. methane, or an oxygen-containing hydrocarbon, e.g. methanol. The CO<sub>2</sub> reduction product so obtained can be reused as fuel.

In a more specific aspect of this invention, there is provided a recycling process for the regeneration of CO<sub>2</sub> gas, which comprises the following steps: (1) an absorption step in which CO<sub>2</sub> gas in the combustion gas of fossil fuel is absorbed in a solution containing an alkaline earth metal compound; (2) a step in which CO<sub>2</sub> gas is recovered to regenerate the absorbent by decomposing the carbonate and/or bicarbonate of the absorbent formed in the absorption step; (3) a reduction step in which CO<sub>2</sub> gas thus recovered is reduced with hydrogen into a hydrocarbon or oxygen-containing hydrocarbon such as methane or methanol; and (4) a recirculation step in which the product of the reduction step is returned to a fossil fuel combustion furnace.

In a still further aspect of this invention, there is also provided a recycling system for the regeneration of CO<sub>2</sub> gas as a system to attain the objects described above. The recycling system comprises a means for bringing flue gas, which contains CO<sub>2</sub> gas and SO<sub>x</sub> gas, into contact with an absorbent containing an alkaline earth metal compound, thereby recovering CO<sub>2</sub> gas and SO<sub>x</sub> gas, as the carbonate and sulfite, respectively, of the alkaline earth metal; a means for feeding the absorbent to the recovery means; a means for decomposing the carbonate of the alkaline earth metal, out of the carbonate of the alkaline earth metal and the sulfite of the alkaline earth metal, into CO<sub>2</sub> gas and the alkaline earth metal compound; and a means for reducing the resulting CO<sub>2</sub> gas with hydrogen, thereby producing a CO<sub>2</sub> reduction product for regeneration.

According to the present invention, the quantity of CO<sub>2</sub> gas to be discharged can be reduced using unlimited and clean solar energy while still operat-

ing existing thermal power systems. The present invention, therefore, can become a basic countermeasure against the green house effect.

## BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become apparent from the following description and the appended claims taken along with the accompanying drawings, in which:

FIG.1 is a block diagram of a recycling system for the utilization of CO<sub>2</sub> gas according to one typical embodiment of the present invention; and

FIG.2 to FIG. 7 are block diagrams of recycling systems according to other embodiments of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The means for recovering CO<sub>2</sub> gas and SO<sub>x</sub> gas is provided with at least one absorbing tower. This means may be constructed such that both CO<sub>2</sub> gas and SO<sub>x</sub> gas can be recovered in a common absorbing tower. This means can be equipped with two or more absorbing towers.

In the recycling system according to the present invention, it is preferable that a means for separating the carbonate of the alkaline earth metal and the sulfite of the alkaline earth metal from each other be installed. The absorbing tower itself may of course be constructed to achieve this separation too.

The absorbent-feeding means can reuse, as an absorbent, an alkaline earth metal compound obtained by decomposition.

The absorbent-feeding means may be equipped with a device for measuring the pH at a discharge port of the carbonate and the sulfite of the alkaline earth metal in the absorbing tower and with a feed controller for controlling the feed quantity of the absorbent. The absorbent-feeding means controls the feed quantity of the absorbent to maintain a pH at which at least one of the compounds, either the carbonate or the sulfite, is present in a solid form.

In the present invention, the carbonate may be either the carbonate or the bicarbonate.

As an absorbent, an alkaline earth metal compound can be used, with a calcium compound being especially preferred. As a calcium compound, it is preferable to select at least one compound from the group consisting of calcium carbonate, calcium oxide and calcium hydroxide. Minerals composed principally of at least one of the above compounds, such as limestone, can also be

used. Incidentally, these compounds are used in a slurry form. The slurry concentration may be, for example, 2-30%, preferably 5-15%.

It is preferable to feed an absorbent in a quantity substantially equal to the stoichiometric quantity required for the conversion of sulfurous acid gas and CO<sub>2</sub> gas, which have been absorbed and removed from the flue gas, to calcium sulfite and calcium bicarbonate, respectively.

According to the method of the present invention, a slurry composed of calcium sulfite particles and a calcium bicarbonate solution can be obtained after the absorption step, whereby the separation of the bicarbonate from the sulfite or vice versa is very easy.

Upon attaining the conditions described above, it is desirable to control the feed quantity of the absorbent so that the pH of the absorbing solution is maintained at about 8-10 at the end of the absorption step.

As a heat source for the decomposition and reduction steps for the bicarbonate and the carbonate, the heat of the combustion gas and waste heat available inherently from the fossil fuel burning facility can be utilized.

Heat energy of about 100°C is necessary for the bicarbonate decomposition step, heat energy of about 900°C for the carbonate decomposition and heat energy of about 200-500°C for the CO<sub>2</sub> gas reduction step. Use of various waste heat as the above heat energy can enhance the effects of the present invention.

When calcium hydroxide is employed as an absorbent, it is preferable to feed the absorbent in a quantity substantially equal to the stoichiometric quantity required for the conversion of sulfurous acid gas and CO<sub>2</sub> gas, both absorbed and removed from flue gas, to calcium sulfite and calcium carbonate, respectively.

Use of calcium hydroxide in the method of the present invention can bring about a particularly high CO<sub>2</sub> absorbing capacity because, in addition to its high capacity to absorb CO<sub>2</sub> gas and sulfurous acid gas, the absorbing solution still has a CO<sub>2</sub>-absorbing capacity when it is taken out from the absorption step.

Upon attaining the above conditions, the feed quantity of the absorbent is controlled so that the pH of the absorbing solution at the end of the absorption step is maintained, at about 10.5 or higher, preferably about 12.

Calcium sulfite and calcium carbonate are separated from their slurry obtained in the absorption step. Then calcium sulfite is oxidized into gypsum, while calcium carbonate is decomposed into calcium oxide and CO<sub>2</sub> gas. The resulting calcium oxide is hydrated into calcium hydroxide, which can be utilized again as an absorbent.

A mixed slurry of calcium sulfite and calcium carbonate, said mixed slurry having been obtained in the absorption step, is oxidized into a slurry of gypsum and calcium carbonate. Then, gypsum and calcium carbonate are separated. The resulting calcium carbonate is decomposed into calcium oxide and CO<sub>2</sub> gas, whereas calcium oxide is converted by hydration into calcium hydroxide, which can be used again as an absorbent.

In this method, calcium carbonate and gypsum are separated. There is a large difference in particle size between them (the particle size of gypsum is much larger) so that the separation in this step is easily facilitated. The separation can be conducted advantageously by a simple means such as a fluid cyclone. To oxidize calcium sulfite, ozone oxidation or oxidation by hydrogen peroxide is effective as well as air oxidation.

In the present invention, two absorbing towers may be employed, one for the absorption of sulfurous acid gas only and the other for the absorption of CO<sub>2</sub> gas only, whereby calcium sulfite is obtained from the former tower and calcium bicarbonate from the latter tower. In this case, the subsequent step of mutual separation of the sulfite and the bicarbonate can be omitted. As an alternative, it is also possible to design such that calcium sulfite and calcium carbonate are obtained from the former tower and the latter tower, respectively. This makes it unnecessary to separate the sulfite and the carbonate from each other.

As a further alternative, it may be possible to construct a single absorbing tower which has the functions of two towers, for example, by subjecting flue gas and an absorbing solution to countercurrent contact, obtaining calcium sulfite and calcium bicarbonate from a vertically-intermediate part of the absorbing tower and drawing calcium sulfite and calcium bisulfite from a bottom part of the tower.

As the reduction means, it is preferable to use a catalyst composed of at least one of alumina, silica and titania as a carrier component, at least one of nickel, iron, copper, chromium, zinc, ruthenium and palladium as an active component and at least one of lanthanum, cerium and yttrium as a cocatalyst component.

As conditions desirable for the reaction in the presence of the catalyst described above, a reaction temperature of 200-500°C and pressure of 1-50 atm. are desired. When methanol is produced, the catalyst may be free of any carrier.

To the solution or slurry of the absorbent, a metal complex such as ethylenediaminetetraacetic acid, citric acid or nitrilotriacetic acid can be added.

The addition of such a complex makes it possible to absorb NO<sub>x</sub>, thereby serving the further advantage of simultaneously removing the NO<sub>x</sub>.

The present invention permits the construction of a system wherein a boiler is provided to burn fossil fuel, the resulting flue gas is passed to the absorbing tower and the boiler uses as a part of its fuel a hydrocarbon or oxygen-containing hydrocarbon produced by the regeneration means described above. As an example, this system can be incorporated into a thermal power plant system.

A water electrolyzer is usable as a means for producing the hydrogen to be used in the reduction of CO<sub>2</sub> gas. As a power source for the electrolysis, a solar cell can preferably be employed.

Incidentally, there are other hydrogen-producing means. Those producing CO<sub>2</sub> gas together with hydrogen are contrary to the objects of this invention and are therefore not suitable.

The recycling system for the regeneration of CO<sub>2</sub> gas according to the present invention can be operated using electric power from a solar cell during daytime and any surplus power from the thermal power plant at night.

Taking by way of example a thermal power plant of 1 million kW generation capacity, one example of a simplified model of the recycling system for the regeneration of CO<sub>2</sub> gas will now be described.

In such a power plant, the discharge quantity of CO<sub>2</sub> gas is expected to be 455 t/h. Assuming that 91 t/h of the CO<sub>2</sub> gas, amounting to 20%, will be treated, the light-receiving area of a solar cell which is used to produce electric power for obtaining hydrogen by electrolysis, which will in turn be used for the reduction of CO<sub>2</sub> gas, may be about 5 million square meters at 10% energy conversion efficiency. Such a treatment will result in the production of  $4.3 \times 10^3$  kcal ( $5 \times 10^5$  kW) in the form of regenerated fuel.

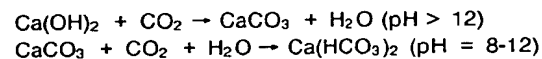
Effects of the present invention, particularly effects of the absorbent, will hereinafter be described.

As described above, methods using an aqueous solution of an alkaline metal salt such as potassium carbonate or sodium carbonate as an absorbent for CO<sub>2</sub> gas have been known. The above absorbent is good for acid gases such as CO<sub>2</sub> gas and sulfurous acid gas, but a sulfite formed by the absorption of sulfurous acid gas and the sulfate formed by the oxidation of the sulfite does not have a CO<sub>2</sub>-absorbing capacity and in addition, they are dissolved in water along with the bicarbonate formed by the absorption of the CO<sub>2</sub> gas. The sulfite and sulfate, therefore, cannot easily be separated from the bicarbonate.

One of features of the present invention resides in ingeniously utilizing characteristic properties of the carbonate, sulfite and sulfate of an alkaline earth metal to permit easy separation of the carbonate and/or the bicarbonate from the sulfite

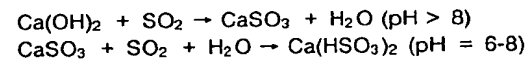
and/or the sulfate and also the regeneration of the absorbent from the carbonate and/or bicarbonate (production of concentrated CO<sub>2</sub> gas) or in the fact that conditions enabling the above-mentioned separation and regeneration have been selected for the absorption and regeneration of CO<sub>2</sub> gas by a calcium compound.

Upon absorption of CO<sub>2</sub> gas, calcium hydroxide first changes to calcium carbonate. Calcium carbonate then absorbs CO<sub>2</sub> gas to form calcium bicarbonate.



At pH 8-12, both calcium carbonate and calcium bicarbonate exist. At pH 8 or lower, only calcium bicarbonate exists. Owing to the extremely low solubility of calcium carbonate, a large majority of calcium carbonate is present in a solid form. On the other hand, calcium bicarbonate exists in the form of a solution because of its high solubility. Their separation is therefore easy.

Sulfurous acid gas also contained in the combustion gas similarly reacts with a calcium salt.



At pH 6-8, both calcium sulfite and calcium bisulfite exist. At pH 6 or lower, only calcium bisulfite exists. Owing to the extremely low solubility of calcium sulfite, a large majority of calcium sulfite exists in a solid form. On the other hand, calcium bisulfite exists in the form of a solution because of its high solubility. Accordingly, their separation is easy.

In a system in which calcium sulfite and calcium carbonate coexist, they are both in a solid (particulate) form at pH 10 or higher. They can, however, be separated according to the difference in particle size or specific gravity. At pH 8-10, the sulfite exists as calcium sulfite in a solid form, while the carbonate exists as calcium bicarbonate in the form of a solution. They can therefore be separated easily. At pH 8 or lower, calcium bicarbonate and calcium bisulfite coexist for the first time in a solution and, hence, it is difficult to separate them from each other.

Accordingly, a calcium salt formed by sulfurous acid gas and another calcium salt formed by CO<sub>2</sub> gas can be separated from each other when sulfurous acid gas and CO<sub>2</sub> gas are absorbed simultaneously by using a slurry of an alkaline earth metal compound, particularly, a calcium compound such as calcium hydroxide or calcium carbonate. The calcium salt formed by CO<sub>2</sub> gas can be decomposed to recover CO<sub>2</sub> gas at a high concentration

and can also be regenerated as an absorbent.

The absorption step of the present invention has been designed in view of the properties of such an alkaline earth metal compound, particularly a calcium compound such as calcium hydroxide or calcium carbonate, for CO<sub>2</sub> gas and sulfurous acid gas.

Taking as an example the application of the present invention to the regeneration of CO<sub>2</sub> gas by its separation and recovery from combustion gas emitted from the boiler, the present invention will hereinafter be described in detail.

#### [Example 1]

FIG. 1 is the block diagram showing the arrangement of the equipments in the CO<sub>2</sub> gas recycling system as one embodiment of the present invention.

This embodiment is equipped with a boiler 2 for burning fossil fuel 1, which is a fuel containing at least carbon as a component, such as coal or oil; a fuel gas treatment sub-system for subjecting the combustion gas from the boiler 2 to NO<sub>x</sub> reduction and also to desulfurization and decarbonization; and a reduction treatment sub-system in which CO<sub>2</sub> separated as a result of the carbonization is reduced. There are some differences in the construction of each of the sub-systems between this embodiment and subsequent embodiments, although they are principally the same. Basically, the following description is commonly applicable to the other embodiments which will be described later. Description of common functional components will therefore be omitted to avoid repetition as much as possible.

The flue gas treatment sub-system is equipped with an NO<sub>x</sub> reduction unit 3, which conducts NO<sub>x</sub> removal; an absorbing tower 10, which functions as a means for absorbing SO<sub>x</sub>, particularly SO<sub>2</sub>, and also CO<sub>2</sub> gas; a thickener 12, which functions as a means for separating a solid component (calcium sulfite) and a liquid component (calcium bicarbonate) from each other, said components having been obtained in the absorbing tower 10; an oxidizing tank 13 which oxidizes calcium sulfite to form gypsum; a dewatering tank 14 which dewateres the resulting gypsum; and a decomposition tank 15 which functions as a means for decomposing calcium bicarbonate to obtain CO<sub>2</sub> gas.

Furthermore, the flue gas treatment sub-system has, as absorbent-feeding means, a pH measuring device 21 which measures the pH of the absorbing solution discharged from the absorbing tower 10 and a feed controller 22 which controls the feeding of calcium carbonate to the absorbing tower 10 according to the pH of the absorbing solution measured by the pH measuring device 21.

The feed controller 22, although not illustrated in FIG. 1, is equipped with a mixer which mixes a replenishing calcium carbonate slurry with a recycled calcium carbonate slurry from the reduction treatment sub-system which will be described below; a pump for supplying the mixed slurry to the absorbing tower 10; and a control unit which controls the mixer and the pump.

The absorbing tower 10 may be provided, if necessary, with a recirculating means (unillustrated), such as a pump, for the recirculation of the internal absorbing solution. Another pump or the like may also be provided, as needed, to discharge the absorbing solution to the outside.

The reduction sub-system comprises a reducing tower 4 in which CO<sub>2</sub> gas obtained in the decomposition tank 15 is subjected to reduction with hydrogen to produce a fuel such as methane; a water electrolyzer 5, which produces hydrogen to be used in the above reduction; and a solar cell 6, which functions as an electric source for supplying d.c. power to the water electrolyzer 5. Packed in the reducing tower 4 is a catalyst, that is, a catalyst composed of alumina as a carrier component, nickel as an active component and lanthanum as a cocatalyst component.

In the present embodiment, calcium carbonate obtained upon separation of CO<sub>2</sub> gas in the flue gas treatment sub-system is fed to the absorbing tower 10 for reuse. On the other hand, methane or the like obtained in the reduction sub-system is fed to the boiler 2 for reuse.

The operation of each sub-system of the system according to this embodiment will hereinafter be described.

Combustion gas, which has been formed by burning fossil fuel 1 in the boiler 2, is subjected to NO<sub>x</sub> removal in the NO<sub>x</sub> reduction unit 3 as needed, and the resulting flue gas containing sulfurous acid gas and CO<sub>2</sub> gas is introduced into the absorbing tower 10. In the absorbing tower 10, the flue gas is brought into contact with a calcium carbonate slurry, which serves as an absorbent, to allow the absorbent to absorb both the sulfurous acid gas and the CO<sub>2</sub> gas. The flue gas from which both the gases have been removed is then discharged from the absorbing tower 10.

In the absorbing tower 10, an absorbing solution (slurry) containing calcium sulfite and calcium bicarbonate is obtained by controlling the feed quantity of the absorbent. The feed quantity is controlled to bring the flue gas into contact with the absorbent in a quantity substantially equal to the stoichiometric quantity required for the conversion of sulfurous acid gas and CO<sub>2</sub> gas, which are to be absorbed and removed from the flue gas, to calcium sulfite and calcium bicarbonate, respectively. In practice, the pH of the absorbing solution is

measured by the pH measuring device 21 and, based on the measuring result, the feed quantity of the absorbent is controlled by the feed control unit 22 so that the pH of the absorbing solution is maintained at about 8.

The absorbing solution is separated in the thickener 12 into solid calcium sulfite and a calcium bicarbonate solution. In the oxidizing tank 13, the calcium sulfite is oxidized with air or the like into gypsum, which is then discharged from the system after having been dewatered in the dewatering tank 14.

On the other hand, the resulting calcium bicarbonate solution is introduced into the decomposition tank 15, where it is decomposed into CO<sub>2</sub> gas and calcium carbonate. The decomposition of the solution is conducted under heat and the resulting calcium carbonate is returned as an absorbent to the absorbing tower 10 together with fresh calcium carbonate which is fed additionally. The thermal decomposition requires a temperature of about 100°C. The flue gas can be used as the heat source for this process.

The decomposition of calcium bicarbonate can be conducted by changing a gypsum-forming mother liquor as needed. In this case, gypsum is produced together with CO<sub>2</sub> gas. Gypsum is fed to the absorbing tower together with calcium carbonate, and then discharged from the system with the gypsum produced above by the oxidation of calcium sulfite.

Highly-concentrated CO<sub>2</sub> gas formed in the decomposition tank 15 is introduced into the reducing tower 4, and is converted to methane, methanol or the like with hydrogen obtained by hydrolysis in the water electrolyzer 5 using, for example, electric power from the solar cell 6. The reduction product is used as fuel for the boiler.

#### [Example 2]

FIG. 2 is a block diagram of a CO<sub>2</sub> gas recycling system according to another embodiment of the present invention.

This embodiment is different from the embodiment of Example 1 in the employment of calcium hydroxide as an absorbent in the flue gas treatment sub-system. Namely, the flue gas treatment sub-system of this embodiment comprises, in addition to the units of the embodiment of Example 1, a dewatering device 16 which removes water from calcium carbonate formed in the decomposition tank 15; another decomposition tank 17, in which the dewatered calcium carbonate is heated and decomposed to obtain CO<sub>2</sub> gas and calcium oxide; and a hydrating tank 18 in which the calcium oxide formed in the decomposition tank 17 is hydrolyzed with water obtained in the dewatering device 16 to

produce calcium hydroxide. The dewatering device 16, decomposition tank 17 and hydrating tank 18 are all installed after the decomposition tank 15. Incidentally, the CO<sub>2</sub> gas obtained in the decomposition tanks 15 and 17 is introduced into the reducing tower 4.

The operation of each sub-system of the system according to this example will hereinafter be described.

In FIG. 2, flue gas containing sulfurous acid gas and CO<sub>2</sub> gas is, in the absorbing tower 10, brought into contact with a calcium hydroxide slurry, which serves as an absorbent, to remove sulfurous acid gas and CO<sub>2</sub> gas. Similarly to Example 1, an absorbing solution (slurry) containing calcium sulfite and calcium bicarbonate is obtained from the absorbing tower 10 by controlling the feed quantity of the absorbent. Namely, the feed quantity of the absorbent is controlled so that the flue gas can be brought into the absorbent in a quantity substantially equal to the stoichiometric quantity required to convert sulfurous acid gas and CO<sub>2</sub> gas, which are to be absorbed and removed from the flue gas, to calcium sulfite and calcium bicarbonate, respectively. In practice, the pH of the absorbing solution is measured by the pH measuring device 21, and the feed quantity of the absorbent is controlled by the feed control unit 22 so that the pH of the absorbing solution is maintained at about 8.

The absorbing solution is likewise separated, in the thickener 12, into solid calcium sulfite and a calcium bicarbonate solution. Calcium sulfite is oxidized into gypsum with air or the like in the oxidizing tank 13. The gypsum is then discharged from the system after having been dewatered in the dewatering tank 14. The resulting calcium bicarbonate solution is, on the other hand, introduced into the decomposition tank 15, in which it is thermally decomposed into CO<sub>2</sub> gas and calcium carbonate or, if a gypsum-forming mother liquor is added as needed, into CO<sub>2</sub> gas and gypsum.

The above procedures are conducted in a similar manner to Example 1, except that slaked lime is used as an absorbent.

In this example, calcium carbonate produced in the decomposition step is dewatered by the dewatering device 16, followed by the thermal decomposition into CO<sub>2</sub> gas and calcium oxide in the decomposition tank 17. The resulting calcium oxide is hydrated, in the hydrating tank 18, with water obtained by the dewatering device 16 to yield calcium hydroxide, which is then returned to the absorbing tower together with calcium hydroxide thus replenishing the system.

The resulting CO<sub>2</sub> gas produced as a result of the decomposition of calcium bicarbonate is introduced into the reducing tower 4 together with hy-

drogen and, in a similar manner to Example 1, they are both reduced and recycled.

In this example, the decomposition of calcium carbonate requires a high temperature of about 900 °C. Calcium hydroxide is, however, superior to calcium carbonate in being able to absorb CO<sub>2</sub> gas and sulfurous acid gas, thereby bringing about such advantages that the absorbing tower 10 can be reduced in size, and the recirculation velocity of the absorbing solution inside the absorbing tower can be lowered. In other words, the electric power for the recirculation pump can be reduced.

#### [Example 3]

FIG. 3 is a block diagram of a CO<sub>2</sub> gas recycling system according to a further embodiment of the present invention. This embodiment is different from the embodiment of Example 2 in that calcium sulfite and calcium carbonate are obtained in the absorbing tower 10. In this example, the decomposition tank 15 of Example 2 is omitted so that calcium carbonate discharged from the absorbing tower 10 is fed to the dewatering device 16, while CO<sub>2</sub> gas is decomposed in the decomposition tank.

The operation of each sub-system of the system according to this embodiment will now be described.

In FIG. 3, flue gas containing sulfurous acid gas and CO<sub>2</sub> gas is brought into contact with a calcium hydroxide slurry, which is used as the absorbent, in the absorbing tower 10, whereby sulfurous acid gas and CO<sub>2</sub> gas are eliminated. Then, as in Example 1, the feed quantity of the absorbent is controlled to obtain from the absorbing tower 10 an absorbing solution (slurry) containing calcium sulfite and calcium carbonate. Namely, the quantity of the absorbent is controlled so that the flue gas is brought into contact with the absorbent in a quantity substantially equal to the stoichiometric quantity required to convert sulfurous acid gas and CO<sub>2</sub> gas, which are absorbed and removed from the flue gas, to calcium sulfite and calcium carbonate respectively. In practice, the pH of the absorbent is measured by the pH measuring device 21, and the feed quantity of the absorbent is controlled by the feed control unit 22 so that the pH of the absorbent is maintained at around at least 10.5, preferably about 12.

The absorbing solution is separated into calcium sulfite and calcium carbonate in the decomposition tank 12. The resulting calcium sulfite is, in the oxidizing tank 13, oxidized by air or the like into gypsum, which is dewatered in the dewatering tank 14 and then discharged from the system. While calcium carbonate is thermally decomposed into CO<sub>2</sub> gas and calcium oxide in the decomposition

tank 17, after having been dewatered in the dewatering device 16. As an alternative, a gypsum-forming mother liquor may be charged as needed so that calcium carbonate is decomposed into CO<sub>2</sub> gas and gypsum.

Calcium oxide is hydrated, in the hydration tank 18 with water obtained from the dewatering device 16, thereby forming calcium hydroxide. The resulting calcium hydroxide is fed to the absorbing tower 10, together with calcium hydroxide thus replenishing the system.

The resulting CO<sub>2</sub> gas is introduced into the reducing tower 4 and, in a similar manner to Example 1, reduced and then recycled.

In this example, the decomposition of calcium carbonate requires a high temperature of about 900 °C. However, a particularly high CO<sub>2</sub>-absorbing capacity is obtained, because calcium hydroxide has an excellent CO<sub>2</sub> gas absorbing capacity and sulfurous acid gas and, moreover, the absorbing solution can be drawn out from the absorbing tower in a state still retaining a CO<sub>2</sub>-absorbing capacity. Accordingly, this embodiment has the advantages that the absorbing tower can be reduced in size and the recirculation velocity of the absorbing solution inside the absorbing tower can be lowered, in other words, the electric power for the recirculation pump can be reduced.

#### [Example 4]

FIG. 4 is a block diagram of a CO<sub>2</sub> gas recycling system according to a still further embodiment of the present invention.

This example is a variation of Example 3.

In FIG. 4, the system of this embodiment is similar to that of the embodiment shown in FIG. 3 until an absorbing solution (slurry) containing calcium sulfite and calcium carbonate is obtained from the absorbing tower 10.

Namely, this embodiment is different from that of Example 3 in that the oxidizing tank 13 is arranged before the thickener 12 in order to oxidize the absorbing solution, which contains calcium sulfite and calcium carbonate, into gypsum and calcium carbonate. This is followed by the separation of the resulting gypsum and calcium carbonate from each other and then, by the decomposition of calcium carbonate.

The operation of each sub-system in this example will now be described.

The absorbing solution (slurry) from the absorbing tower 10, containing calcium sulfite and calcium carbonate, is oxidized in the oxidizing tank 13 into gypsum and calcium carbonate. This is followed by their mutual separation in the thickener 12. Gypsum is discharged from the system after having been dewatered by the dewatering tank 14.



Calcium carbonate is dewatered by the dewatering device 16, and is then thermally decomposed into CO<sub>2</sub> gas and calcium oxide in the decomposition tank 17. As an alternative, a gypsum-forming mother liquid may be charged as needed so that calcium carbonate can be decomposed into CO<sub>2</sub> gas and gypsum.

Calcium oxide is hydrated, in the hydration tank 18, with water obtained by the dewatering device 16 in order to form calcium hydroxide, which is then fed to the absorbing tower 10 together with calcium hydroxide, thus replenishing the system.

The resulting CO<sub>2</sub> gas is introduced into the reducing tower 4 where its reduction and recycling are conducted as in Example 1.

In this example, calcium carbonate and gypsum are separated from each other in the thickener 12. The separation of calcium sulfite and calcium carbonate by this embodiment is easier than that by the embodiment of Example 3, because there is a large difference in particle size between calcium carbonate and gypsum (gypsum has a much larger particle size).

#### [Example 5]

FIG. 5 is a block diagram of a CO<sub>2</sub> gas recycling system according to a still further embodiment of the present invention.

This embodiment has obviated the mutual separation step of the sulfite and the carbonate, which is required in each of the embodiments previously described, by employing two absorbing towers. One tower is used for the absorption of sulfurous acid gas only and the other for the absorption of CO<sub>2</sub> gas only. Namely, the system of this embodiment has one absorbing tower 10 for desulfurization and another absorbing tower 11 for decarbonization in the flue gas treatment sub-system thereof. After the absorbing tower 10, the oxidizing tank 13 and the dewatering tank 14 are arranged. After the absorbing tower 11, the decomposition tank 15 is disposed. The thickener 12, which is included in each of the above embodiments is omitted. Further, these absorbing towers 10 and 11 are each equipped with the pH measuring device 21 and the feed control unit 22. The remaining construction of this embodiment is similar to that of the embodiment of Example 1.

The operation of each sub-system of the system of this embodiment will hereinafter be described.

In FIG. 5, the flue gas is, in the absorbing tower 10, brought into contact with a calcium carbonate or calcium hydroxide slurry to form calcium sulfite. The flue gas is then brought into contact with a calcium carbonate slurry in the absorbing

tower 11, whereby a calcium bicarbonate solution is obtained.

These substances are selectively obtained in the absorbing towers 10 and 11 by controlling the feed quantities of the absorbents. This is similar to the above described embodiments.

The calcium sulfite from the absorbing tower 11 is discharged from the system following the oxidation in the oxidizing tank 13 and the dewatering in the dewatering tank 14.

The calcium bicarbonate is decomposed into calcium carbonate and CO<sub>2</sub> gas in the decomposition tank 15. The former is recycled into the absorbing tower 11, while the latter is fed to the reducing tower 4.

#### [Example 6]

FIG. 6 is a block diagram of a CO<sub>2</sub> gas recycling system according to a still further embodiment of the present invention.

This example is a variation of Example 5. This embodiment has obviated the step for the mutual separation of the sulfite and the carbonate by employing two absorbing towers, one for the absorption of sulfurous acid gas alone, to form calcium sulfite and the other for the absorption of CO<sub>2</sub> gas alone, to form calcium carbonate. Namely, the decomposition tank 15, which is installed in Example 5, has been replaced by the dewatering device 16, the decomposition tank 17 and the hydration tank 18, as in Example 3.

The operation of each sub-system of the system according to the embodiment in this example will now be described.

In FIG. 6, the flue gas is first brought into contact with a calcium carbonate or calcium hydroxide slurry in the absorbing tower 10 in order to form calcium sulfite. The flue gas is then brought into contact with a calcium hydroxide slurry in the absorbing tower 11 in order to form a calcium carbonate solution.

These substances are selectively obtained in the absorbing towers 10 and 11 by controlling the feed quantities of the absorbents. This is similar to each embodiment described above.

The calcium sulfite from the absorbing tower 11 is discharged from the system following the oxidation in the oxidizing tank 13 and the dewatering in the dewatering tank 14.

After having been dewatered in the dewatering tank 16, calcium carbonate is thermally decomposed into CO<sub>2</sub> gas and calcium oxide in the decomposition tank 17. With water which has been obtained in the dewatering tank 16, the calcium oxide is hydrated into calcium hydroxide in the hydration tank 18, which is then recycled to the absorbing tower 11 with calcium hydroxide, thus

replenishing the system. On the other hand, the CO<sub>2</sub> gas is fed to the reducing tower 4.

#### [Example 7]

FIG. 7 is a block diagram of a CO<sub>2</sub> gas recycling system according to a still further embodiment of the present invention.

In this embodiment, a single absorbing tower is designed to perform both the functions of the two absorbing towers in Example 5 or 6. Namely, the flue gas treatment sub-system in this embodiment is equipped with an absorbing tower 10 constructed such that a slurry can be drawn out from both an intermediate part and a bottom part. The thickener 12 is constructed so as to receive the slurry from the intermediate part of the absorbing tower 10, while the oxidizing tank 13 is constructed so that calcium sulfite and calcium bisulfite, from the bottom part of the absorbing tower 10, as well as the thickener 12, can be oxidized there.

The operation of each sub-system of the system according to this embodiment will now be described.

A calcium carbonate slurry is fed from a top part of the absorbing tower 10 and the flue gas is introduced from a lower part thereof, whereby the absorbent and the flue gas are subjected to countercurrent contact. From the intermediate part of the absorbing tower 10, the slurry containing calcium sulfite and calcium bicarbonate and having pH 8 or so is discharged and introduced into the thickener 12. In the thickener 12, calcium sulfite and calcium bicarbonate are separated from each other. The resulting calcium sulfite, together with calcium sulfite and calcium bisulfite discharged from the bottom part, is oxidized into gypsum in the oxidizing tank 13. The calcium bicarbonate is decomposed into calcium carbonate and CO<sub>2</sub> gas in the decomposition tank 15.

The decomposition of calcium bicarbonate can also be conducted by optionally adding a gypsum-forming mother liquor. In this case, gypsum is formed together with CO<sub>2</sub> gas. The resulting gypsum is, together with calcium carbonate, fed to the absorbing tower 10 and then, along with the above gypsum formed above by the oxidation of calcium sulfite, is discharged from the system. Calcium carbonate formed in the decomposition tank 15 is, together with calcium carbonate replenished to the system, recycled to the absorbing tower 10, while the CO<sub>2</sub> gas is fed to the reducing tower 4.

The operation of the system according to the present invention will hereinafter be described in further detail based on one of the embodiments. Namely, an operation example of the embodiment of Example 1 illustrated in FIG.1 will be described. The other embodiments can be operated in a sub-

stantially similar manner.

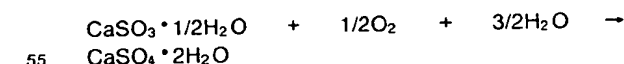
#### [Experiment]

5 The boiler 2, was charged with 29.0 kg/h of coal as fossil fuel 1, and at the same time, a recycled gas containing 12.7 vol% of methane, 47.0 vol% of hydrogen and 10.6 vol% of CO<sub>2</sub> gas from the reducing tower 4 was also charged. They were burned, whereby 311 Nm<sup>3</sup>/h of flue gas containing 12.89 vol% of CO<sub>2</sub> gas and 0.24 vol% of sulfurous acid gas were produced. The resulting flue gas was introduced into the bottom part of the absorbing tower 10 through the NO<sub>x</sub> reduction unit 3.

10 In the absorbing tower 10, ten perforated plates each having an opening rate of 40% were installed at varied stages. From the upper part of the tower 10, 20.0 kg/h of a recycled slurry from the decomposition tank 15, said slurry containing 6.4 wt.% of calcium carbonate, and a replenishing slurry containing 10.0 wt.% of calcium carbonate were fed as a mixture and were then brought into contact with the flue gas in a countercurrent fashion. To a slurry residence zone in the bottom part of the absorbing tower, the pH measuring device 21 was installed to measure the pH of the slurry mixture. Its output was sent to the feed control unit 21, whereby the feed quantity of the recycled slurry was controlled in association with a feed pump for the replenishing slurry to maintain the pH of the slurry mixture in the residence zone at 8.1 or higher. As a result, the feed quantity of the replenishing slurry was 0.31 kg/h.

15 Under the above operation conditions of the absorbing tower 10, 4.5 Nm<sup>3</sup>/h of CO<sub>2</sub> gas and 0.066 Nm<sup>3</sup>/h of sulfurous acid gas were absorbed, while 316 Nm<sup>3</sup>/h of the flue gas was discharged from the stack. From the bottom part of the absorbing tower 10, a slurry of pH 8.1 was discharged at the rate of 328 kg/h. It was then introduced into the thickener 12.

20 A solution containing 9.9 wt.% of calcium bicarbonate was discharged from an upper part of the thickener 12 at the rate of 328 kg/h and was then introduced into the decomposition tank 15. A slurry containing 64.8 wt.% of calcium sulfite was, on the other hand, drawn out from a bottom part of the thickener 12 at the rate of 0.50 kg/h and was then introduced into the oxidation tank 13, in which air was blown into the slurry to oxidize the latter into calcium sulfate (gypsum).



Gypsum was next discharged from the bottom part of the dewatering tank 14 at the rate of 0.51

kg/h and was then separated.

In the decomposition tank 15, calcium bicarbonate was decomposed by the heat, about 350°C, of the flue gas introduced from a point just before the NO<sub>x</sub> reduction unit 3, to cause the recovery of 4.5 Nm<sup>3</sup>/h of CO<sub>2</sub> gas.



The resulting CO<sub>2</sub> gas was introduced into the reducing tower 4 together with 17.9 Nm<sup>3</sup>/h of hydrogen which had been produced in the water electrolyzer 5 using electricity generated from the 100 kW solar cell 6. It was brought into contact with 3 kg of a catalyst composed of nickel, lanthanum and alumina to convert the CO<sub>2</sub> gas to methane, whereby 18.3 Nm<sup>3</sup>/h of gas containing 12.7 vol% of methane, 47.0 vol% of hydrogen and 10.6 vol% of CO<sub>2</sub> gas was obtained.

The resulting gas was recirculated to the boiler 2 and was then burned together with coal. At this time, the output of a generator (not shown) was 100 kW and 316 Nm<sup>3</sup>/h of flue gas containing 35.6 Nm<sup>3</sup>/h of CO<sub>2</sub> gas were emitted from the stack.

#### [Comparative Experiment]

When 100 kW of electricity was generated by a conventional thermal power generation system which was not equipped with any of the thickener 12, the decomposition tank 15, the water electrolyzer 5, the solar cell 6 or the reducing tower 4, the quantity of coal required was 32.2 kg/h and the flue gas emitted from the stack amounted to 282 Nm<sup>3</sup>/h. The quantity of CO<sub>2</sub> gas in the flue gas was 39.5 Nm<sup>3</sup>/h. Namely, the quantity of coal required and the emission of CO<sub>2</sub> each showed an increase of 11%.

The solar cell was employed as an energy source for the reduction sub-system in each of the above embodiments. This invention is however not limited to the use of such a solar cell. For example, the electric power may be obtained from such a solar cell during the daytime and from any surplus power from the thermal power plant at night.

#### Claims

1. A method for the treatment of flue gas containing CO<sub>2</sub> gas and SO<sub>x</sub> gas, which comprises bringing the flue gas into contact with an absorbent containing an alkaline earth metal compound in order to recover the CO<sub>2</sub> gas and the SO<sub>x</sub> gas as the carbonate and the sulfite of the alkaline earth metal, respectively.
2. The method of claim 1, wherein the feed quantity of the adsorbent is controlled so as to

provide a pH at which at least one of the compounds, either the carbonate or the sulfite, is present in a solid form upon recovery of the carbonate and the sulfite.

3. The method of claim 2, further comprising: separating the carbonate of the alkaline earth metal and the sulfite of the alkaline earth metal from each other; decomposing the carbonate into CO<sub>2</sub> gas and the alkaline earth metal compound; and reusing the alkaline earth metal compound as the absorbent and also recovering the CO<sub>2</sub> gas.
4. The method of claim 3, wherein the resulting CO<sub>2</sub> gas is reduced with hydrogen to form a CO<sub>2</sub> reduction product for the utilization.
5. The method of claim 4, wherein the resulting CO<sub>2</sub> reduction product is reused as a fuel.
6. The method of 1, wherein the carbonate is a bicarbonate.
7. The method according to 1, wherein a calcium compound is used as the absorbent.
8. The method of claim 7, wherein the calcium compound is at least one compound selected from the group consisting of calcium carbonate, calcium oxide and calcium hydroxide.
9. The method of claim 2, wherein calcium carbonate is used as the absorbent, said calcium carbonate being fed in a quantity substantially equal to the stoichiometric quantity required to convert the SO<sub>x</sub> gas to calcium sulfite and the CO<sub>2</sub> gas to calcium bicarbonate, thereby obtaining a mixed slurry of calcium sulfite and calcium bicarbonate.
10. The method of claim 9, wherein the pH of the mixed slurry of calcium sulfite and calcium bicarbonate falls within a range of 8-10.
11. The method of claim 2, wherein calcium hydroxide is used as the absorbent, said calcium hydroxide being fed in a quantity substantially equal to the stoichiometric quantity required to convert the SO<sub>x</sub> gas calcium sulfite and the CO<sub>2</sub> gas to calcium carbonate, thereby providing a mixed slurry, of calcium sulfite and calcium carbonate.
12. The method of claim 11, wherein the pH of the mixed slurry of calcium sulfite and calcium carbonate is 10.5 or higher.

13. The method of claim 9, further comprising:  
 separating calcium sulfite and calcium bicarbonate from the mixed slurry of calcium sulfite and calcium bicarbonate;  
 oxidizing the calcium sulfite into gypsum;  
 subjecting the calcium bicarbonate to thermal decomposition to form CO<sub>2</sub> gas and calcium carbonate; and  
 utilizing the resultant calcium carbonate as the absorbent.
14. The method of claim 11, further comprising:  
 separating calcium sulfite and calcium carbonate from the mixed slurry of calcium sulfite and calcium carbonate;  
 oxidizing the calcium sulfite into gypsum;  
 decomposing the calcium carbonate into calcium oxide and CO<sub>2</sub> gas;  
 subjecting the calcium oxide to hydration to obtain calcium hydroxide; and  
 utilizing the resultant calcium hydroxide as the absorbent.
15. The method of claim 11, further comprising:  
 oxidizing the mixed slurry of calcium sulfite and calcium carbonate to obtain a slurry of gypsum and calcium carbonate;  
 separating the calcium carbonate and the gypsum from each other;  
 decomposing calcium carbonate into calcium oxide and CO<sub>2</sub> gas,  
 subjecting the calcium oxide to hydration to obtain calcium hydroxide; and  
 utilizing the calcium hydroxide as the absorbent.
16. A recycling system for the regeneration of CO<sub>2</sub> gas, which comprises:  
 a means for bringing flue gas, which contains CO<sub>2</sub> gas and SO<sub>x</sub> gas, into contact with an absorbent containing an alkaline earth metal compound in order to recover the CO<sub>2</sub> gas and the SO<sub>x</sub> gas as the carbonate and the sulfite, respectively, of said alkaline earth metal ;  
 a means for supplying the absorbent to the recovering means; a means for decomposing the carbonate of the alkaline earth metal, out of the carbonate of the alkaline earth metal and the sulfite of the alkaline earth metal, into CO<sub>2</sub> gas and the alkaline earth metal compound; and  
 a means for reducing the resulting CO<sub>2</sub> gas with hydrogen, thereby producing a CO<sub>2</sub> reduction product.
17. The system of claim 16, wherein the means for recovering CO<sub>2</sub> gas and SO<sub>x</sub> gas is provided with at least one absorbing tower and the CO<sub>2</sub> gas and SO<sub>x</sub> gas are both recovered commonly in the absorbing tower.
18. The system of claim 17, further comprising a means for separating the carbonate of the alkaline earth metal and the sulfite of the alkaline earth metal from each other.
19. The system of claim 16, wherein the absorbent-feeding means reuses the alkaline earth metal compound, which has been obtained by the above decomposition, as the absorbent.
20. The system of claim 16, further comprising a boiler in which fossil fuel is burned with the resulting combustion gas being fed to the absorbing tower, said boiler using as a part of its fuel the CO<sub>2</sub> reduction product produced by the regeneration means.
21. The system of claim 16, wherein the absorbent-feeding means comprises a device for measuring the pH of both the carbonate of the alkaline earth metal and the sulfite of the alkaline earth metal both at a discharge port of the absorbing tower and a feed control unit for adjusting the feed quantity of the absorbent.
22. The system of claim 21, wherein the absorbent-feeding means controls the feed quantity of the absorbent so as to provide a pH at which at least one of the compounds, either the carbonate or the sulfite, can exist in a solid form upon recovery of the carbonate and the sulfite.
23. The system of claim 21, wherein the absorbent-feeding means feeds calcium carbonate as the absorbent and the feed control unit maintains the pH of the mixed slurry of calcium sulfite and calcium bicarbonate within a range of 8-10.
24. The system of claim 21, wherein the absorbent-feeding means feeds calcium hydroxide as the absorbent and the feed control unit maintains the pH of the mixed slurry of calcium sulfite and calcium carbonate slurry at 10.5 or higher.
25. The system of claim 16, further comprising a water electrolyzer as a hydrogen source, and a solar cell as an electric source, for the water electrolysis.
26. An operation method for the system of claim 25, wherein an electric power supplied by the

solar cell is employed during the daytime and any surplus power of the thermal power plant is employed at night.

27. The system of claim 16, wherein the means for recovering CO<sub>2</sub> gas and SO<sub>x</sub> gas is equipped with an absorbing tower for the recovery of CO<sub>2</sub> gas only and another absorbing tower for the recovery of SO<sub>x</sub> gas only.
28. The system of claim 16, wherein the means for recovering CO<sub>2</sub> gas and SO<sub>x</sub> gas is provided with at least one absorbing tower, said at least one absorbing tower being constructed such that the carbonate of an alkaline earth metal is charged from a vertically-intermediate part of the tower and the sulfite of an alkaline earth metal from a bottom part of the tower.

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FIG. 1

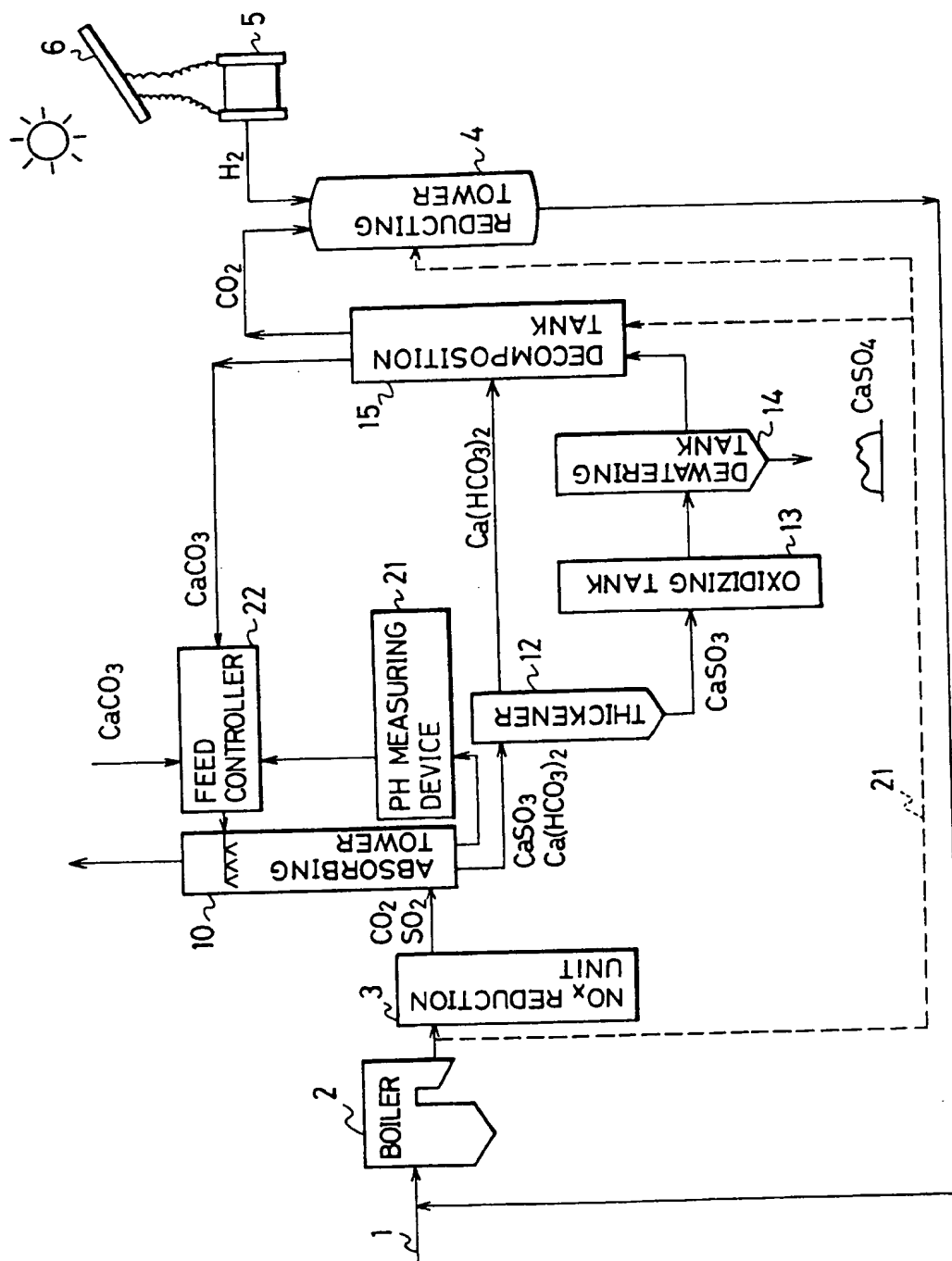


FIG. 2

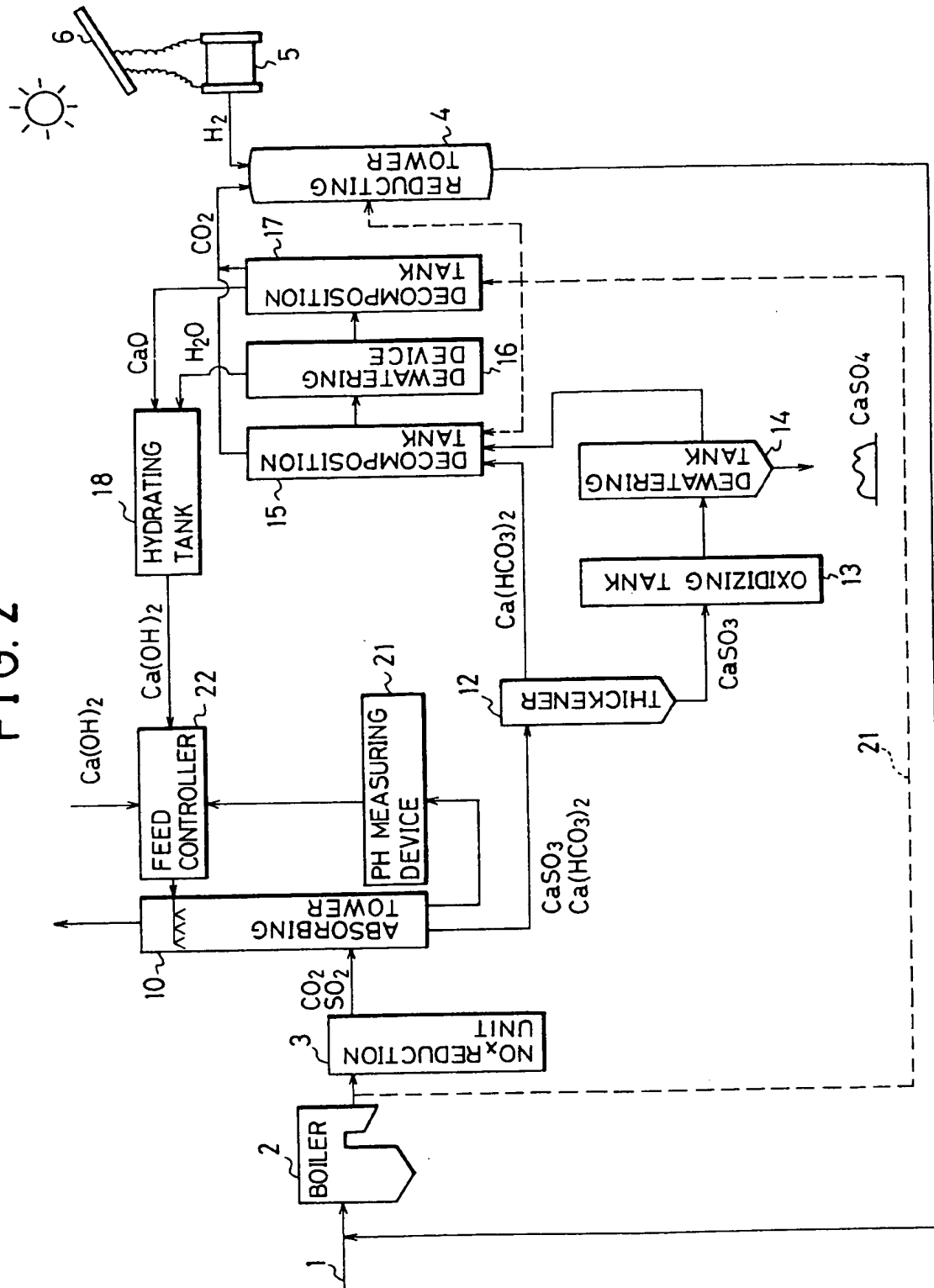


FIG. 3

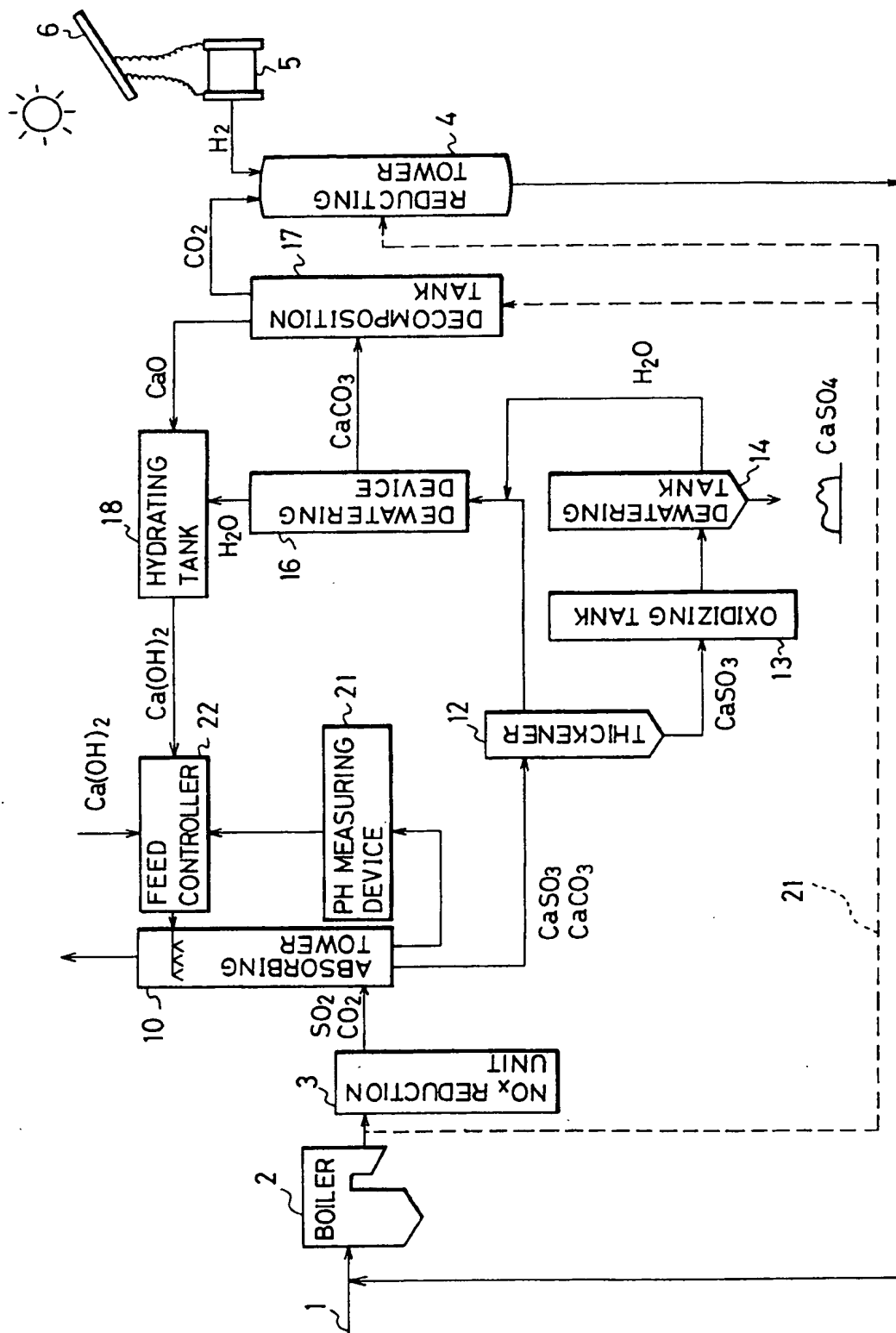




FIG. 4

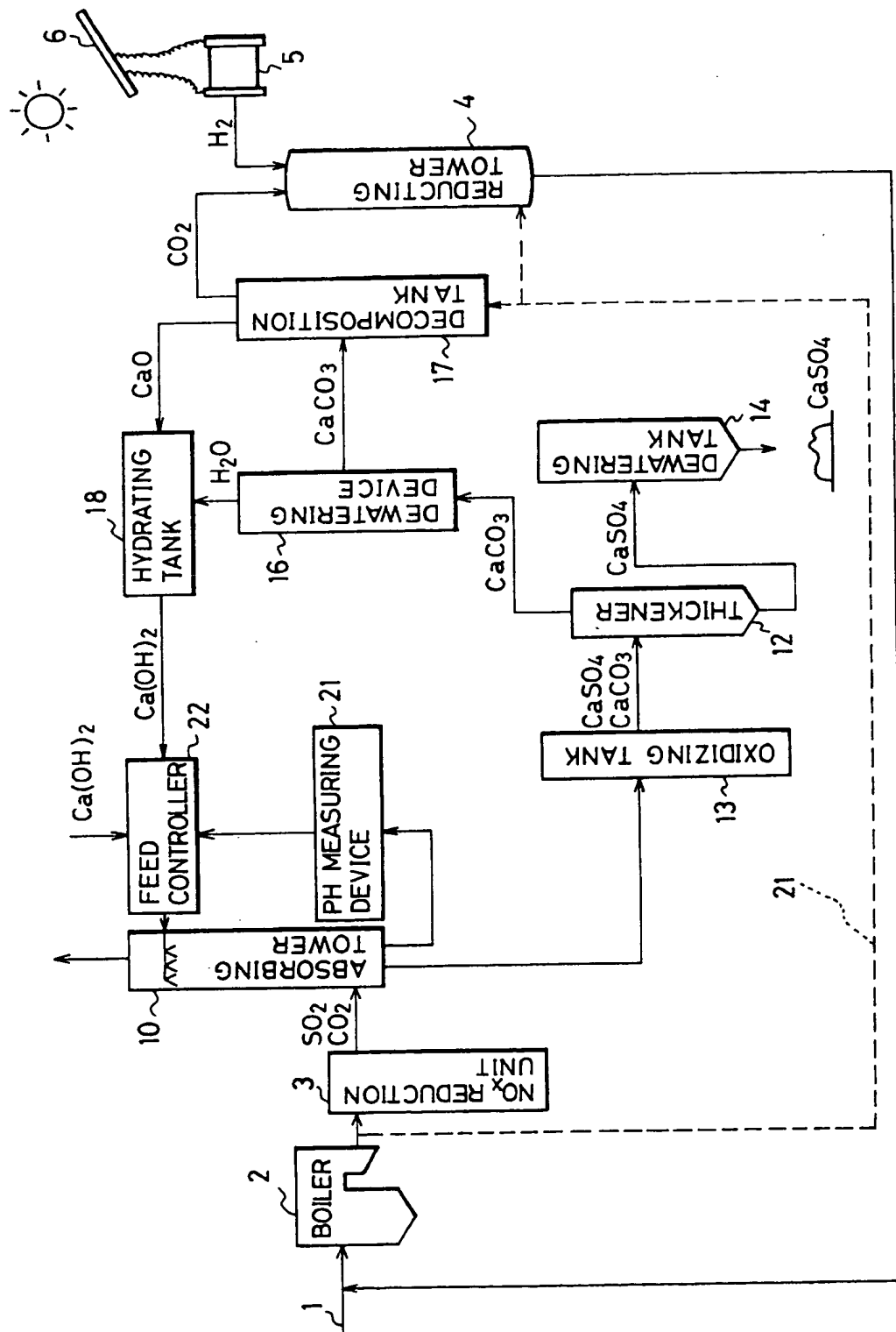


FIG. 5

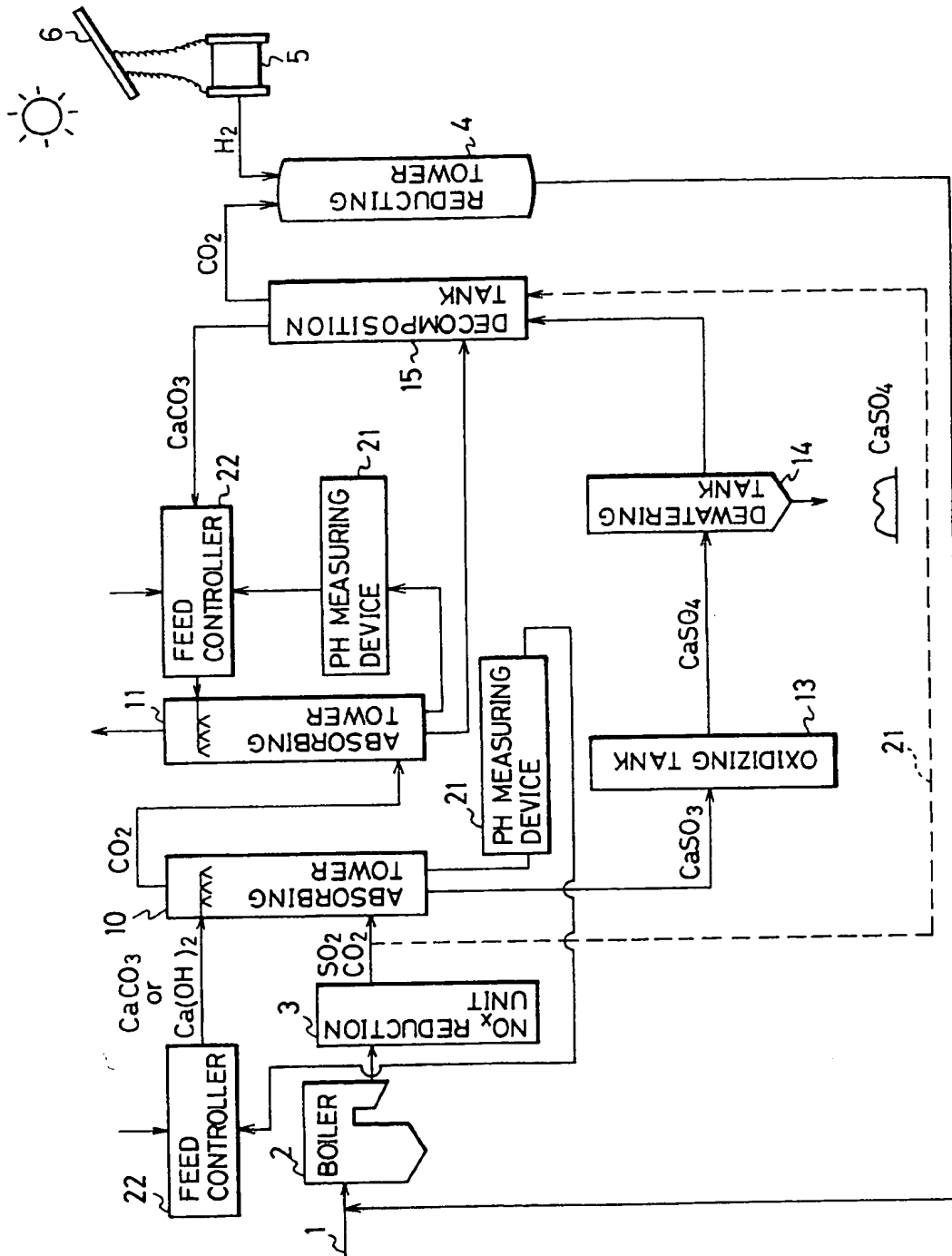


FIG. 6

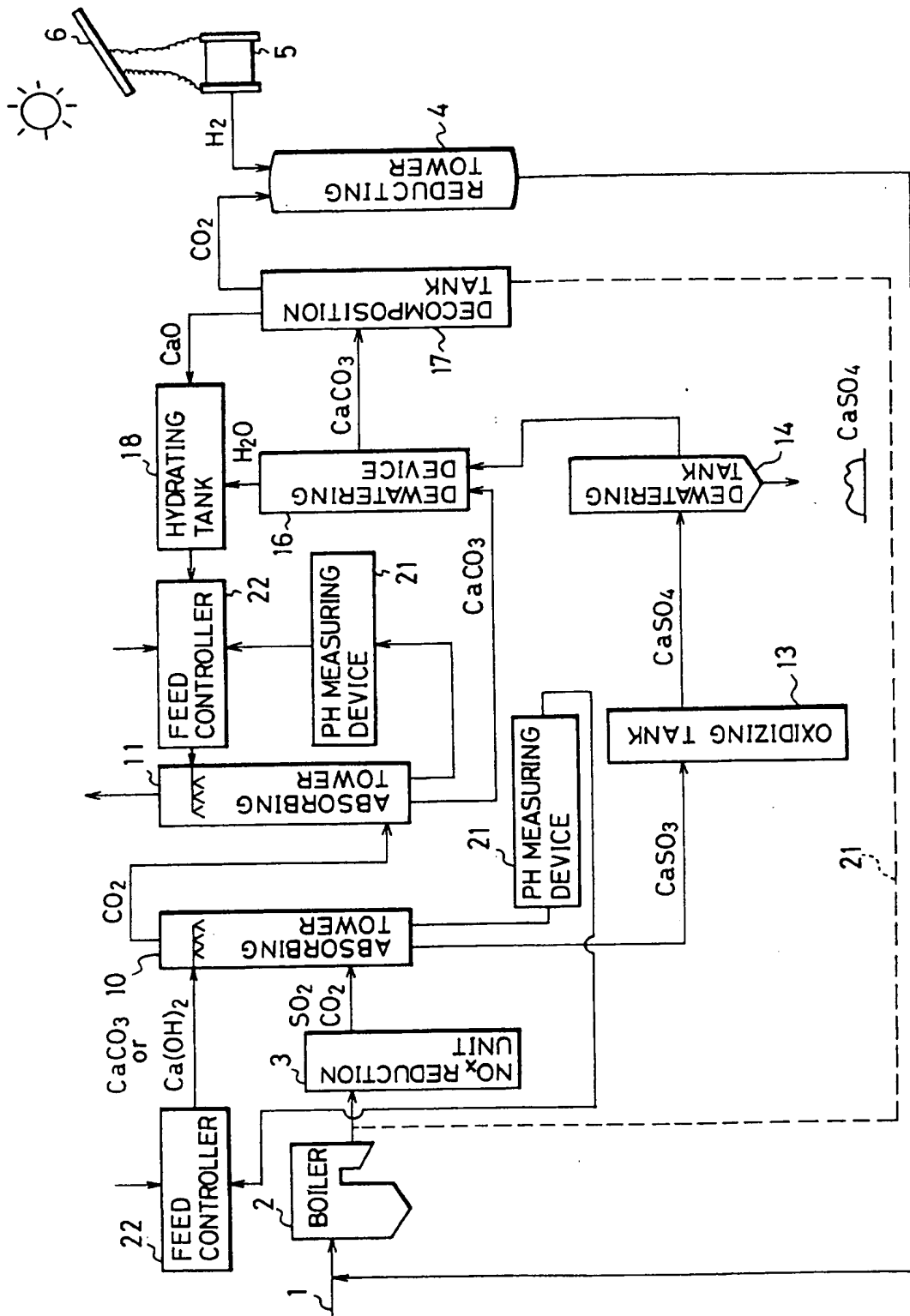
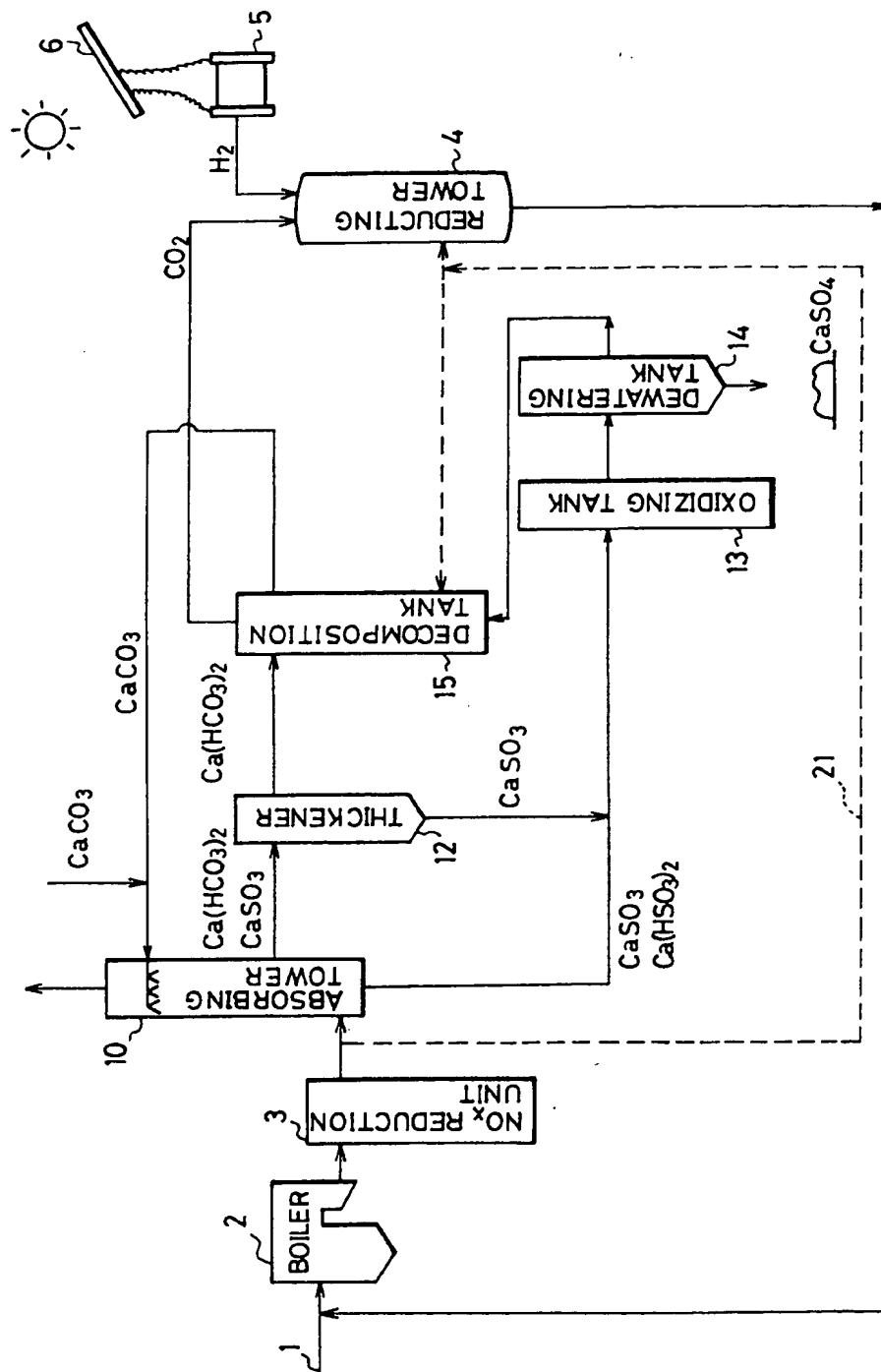


FIG. 7





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## EUROPEAN SEARCH REPORT

Application Number

EP 91 11 9959

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X	WO-A-9 009 225 (KOTA) * Page 1, lines 10-14; page 11, line 16 - page 12, line 22; figures 1,2 *	1,2,6-8 ,11	
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Place of search THE HAGUE		Date of completion of the search 11-02-1992	Examiner EIJKENBOOM A.F.
<b>CATEGORY OF CITED DOCUMENTS</b> X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons * : member of the same patent family, corresponding document			



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## EUROPEAN SEARCH REPORT

Page 2

Application Number

EP 91 11 9959

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 5)
A	US-A-4 510 124 (SCIENCE APPLICATIONS, INC.) * Figure 2; column 5, lines 31-39; column 6, lines 4-51 * -----	1-11, 16 -24	
			TECHNICAL FIELDS SEARCHED (Int. Cl. 5)
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 11-02-1992	Examiner EIJKENBOOM A.F.
<b>CATEGORY OF CITED DOCUMENTS</b>			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	